Space Technology Research Grants

Dynamics and Design of Open, Self-Regulating, Capillary Flow Networks for Space Micropropulsion Applications

Completed Technology Project (2017 - 2021)

Project Introduction

Advances in miniaturization of electronics and MEMS devices enable microsatellites and CubeSats to perform tasks that previously required massive satellites. Low launch costs of these microsatellites will make existing applications cheaper and revolutionize access to space, leading to an explosion of diversity in orbital systems. But a reliable micropropulsion system is needed to allow CubeSats to perform the same orbital maneuvers as traditional satellites, and even be used for swarming and deep-space missions. One promising technology is electrospray micropropulsion. Traditional large-scale electrospray propulsion induces an electric field with a negative electrode above the surface of a conductive propellant, causing emission of ions or droplets. It has been tested successfully in space on the LISA Pathfinder mission. Electrospray micropropulsion miniaturizes this technology; the thrusters are so small and light that you could easily fit five or six in the palm of your hand. A leading design is external-flow microfluidic electrospray propulsion (MEP). Emission technology is advancing steadily, but a key roadblock is the development of a propellant management device (PMD) to regulate flow from storage to the emitters. The laws of fluid dynamics prevent large-scale PMDs with their pumps, valves, and pipes from working at the micro scale. Development of effective micro PMDs is the final technological step required for the electrospray micropropulsion. We propose a novel self-healing microfluidic PMD, and the results of our research will be easily adaptable to other microfluidic projects such as lab-on-a-chip devices for extraplanetary or medical uses, focus beam spectrometers, electron microscopes, and milling devices. An earlier approach to micro PMDs relied on internal wicking, precluding fine control of the design or self-regulatory flow characteristics. Our proposed PMD will consistently and robustly feed propellant to the emitter, automatically adjust for varying emitter conditions, self-heal and resist perturbations, and avoid clogging. This can be accomplished by using external wicking instead of internal flow. Although internal and external capillary wicking are both related to surface tension, they are fundamentally different processes. Internal wicking (flow through a narrow pipe) is well understood. The enclosure forces the flux to be constant in space, so the fluid dynamics are governed by a single parameter (the distance the fluid has wicked) and local flow control is impossible. External wicking (capillary flow with a free surface, e.g. in a groove) is not well understood, but its complexity increases the possibilities for flow control. The existence of a free surface allows flux and local pressure to vary dynamically. And external groove flow is automatically self-healing: fluid avoids regions with too much propellant and flows to underfilled regions, making it a natural fit for PMDs. External flow is also controllable. Unlike internal flow, the free surface can couple both to the geometry of the substrate and external electromagnetic fields; hence flow can be precisely controlled at every point from start to end. This potential for extremely fine fluid control is not trivial; the highly nonlinear partial differential equations governing the dynamics are very difficult to solve. But with thorough analysis and numerical modeling, the power of free surface

Dynamics and Design of Open, Self-Regulating, Capillary Flow Networks for Space Micropropulsion Applications

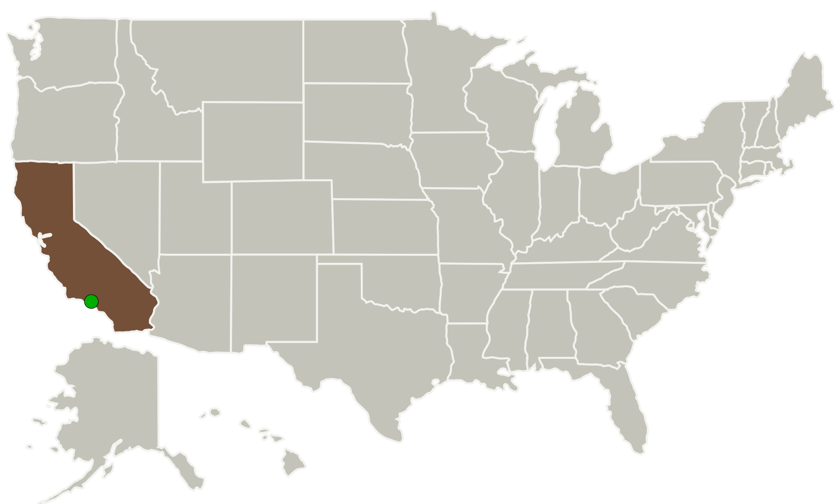
Table of Contents

control can be unlocked. We have proposed designing an external-flow PMD specifically for the MEP. But rather than stop at designing a single PMD for a particular application, we also propose developing a comprehensive analytical and computational toolkit for self-regulating external flow networks. This toolkit will contain analogues of electronic components (resistors, capacitors, etc.) so that fluid management systems for various situations can quickly and easily be developed by considering analogous electronic circuitry.

Anticipated Benefits

Development of effective micro propellant management devices (PMDs) is the final technological step required for electrospray micropropulsion. We propose a novel self-healing microfluidic PMD, and the results of our research will be easily adaptable to other microfluidic projects such as lab-on-a-chip devices for extraplanetary or medical uses, focus beam spectrometers, electron microscopes, and milling devices.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
California Institute of Technology(CalTech)	Lead Organization	Academia	Pasadena, California
Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, California

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

California Institute of Technology (CalTech)

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

Sandra M Troian

Co-Investigator:

Nicholas E White

Dynamics and Design of Open, Self-Regulating, Capillary Flow Networks for Space Micropropulsion Applications

Completed Technology Project (2017 - 2021)

Primary U.S. Work Locations

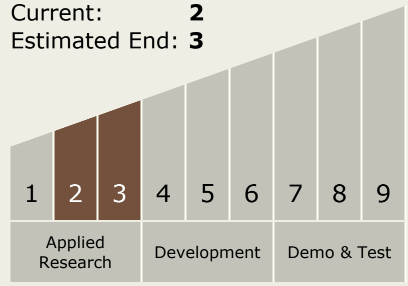
California

Project Website:

https://www.nasa.gov/strg#.VQb6T0jJzyE

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Technology Areas

Primary:

- TX01 Propulsion Systems
  └─ TX01.2 Electric Space Propulsion
    └─ TX01.2.2 Electrostatic

Target Destinations

Earth, The Moon, Mars